Photoelectric Readout Noise and Magnetic Field Sensitivity Limits of NV Centers in Diamond

I Chuprina[1], G Genov[1], C Findler[1,2], J Lang[1,2], P Siyushev[1,3], and F Jelezko[1]

[1] *Institute for Quantum Optics, Ulm University, Ulm, Germany*
[2] *Diatope GmbH, Ulm, Germany*
[3] *Physics, University Hasselt @ IMEC, division IMOMEC, Hasselt, Belgium*
Contact Email: ilia.chuprina@uni-ulm.de

Nitrogen-vacancy (NV) centers in diamond are of great interest for nano- and macro-scale magnetic-field sensing. In most experiments, the NV electron spin state is detected optically through spin-dependent photoluminescence. While this method is robust and experimentally convenient, its sensitivity is constrained by photon shot noise, finite photon collection efficiency, and limited optical contrast. Photoelectrical (PE) spin readout [1,2], in which the spin state is converted into a spin-dependent photocurrent, offers an alternative detection method compatible with electrical integration and on-chip sensor architectures, down to single defect level [3]. However, the noise properties of PE readout and their consequences for magnetic-field sensitivity have not yet been quantitatively established.

In this work [4], we compare conventional optical readout and photoelectrical spin readout for magnetic-field sensing with NV centers in diamond. We perform measurements on both single NV centers and implanted NV ensembles, and demonstrate Ramsey-based magnetometry using PE detection of the NV spin state. To quantify the readout performance, we analyze the PE signal using a Gaussian noise model, extract the corresponding readout efficiency, and derive the resulting magnetic-field sensitivity. We further characterize the electronic noise in the PE detection channel and distinguish technical contributions, such as instrumental noise and electrical crosstalk, from fundamental noise sources, including Johnson-Nyquist noise and electronic shot noise.

Our analysis shows that the present PE implementation is not yet limited by fundamental electronic noise, but rather by technical noise sources in the detection electronics and device environment. Nevertheless, the experimentally extracted parameters allow us to estimate the sensitivity achievable in the Johnson–Nyquist-noise-limited regime. Under such conditions, PE detection could improve magnetic-field sensitivity by approximately one order of magnitude compared with conventional optical readout. These findings define a clear path toward noise-limited PE magnetometry and represent an important step toward on-chip quantum sensors based on electrical spin readout of NV centers in diamond. More broadly, the developed framework can be applied to photoelectrical readout of other optically addressable defects in diamond, silicon carbide, and related solid-state platforms.

References

[1] E Bourgeois, A Jarmola, P Siyushev, *et al.*, Nat. Commun. **6**, 8577 (2015)

[2] E Bourgeois, M Gulka and M Nesladek, Adv. Opt. Mater. **8**, 1902132 (2020)

[3] P Siyushev, M Nesladek, E Bourgeois, *et al.*, Science **363**, 728 (2019)

[4] I Chuprina, G Genov, C Findler, *et al.*, arXiv:2604.20901 (2026)